MAPPING OF STRUCTURES OF SCIENTIFIC KNOWLEDGE – A GENERALIZATION OF CONCEPT MAPS TOOLS AS ALGORITHMIC LANGUAGE.

Mapeamento de Estruturas do Conhecimento Científico – Uma Generalização da Ferramenta Mapas Conceituais como Linguagem Algorítmica.

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Abstract: We present a research methodology developed for the theory of scientific knowledge which use conceptual mapping (Novak, 1990), cognitive science theory (Izqueirdo, 2003), theory of didactic transposition (Chevallard 1982) and algorithmic language. We defend the idea that in particular cases, as in the study of the theory of scientific knowledge that conceptual mapping should be done obeying well-defined rules. Due to certain particularities of how Physical theories are constructed and expressed in terms of Physical laws we will have to generalize the tool "conceptual maps" to describe how the Physical theories are elaborated. This generalization will be called "Mapping of Structures of Scientific Knowledge". With theme the part of physics called blackbody radiation and the theory of Planck's quantization it will be demonstrating the usefulness and effectiveness of this methodology and this tool.
Key Words: Concept Mapping, Didactic Transposition, Cognitive Theory of Science, Science Theaching.

Resumo: Apresentamos aqui uma metodologia de pesquisa desenvolvida para a teoria do conhecimento científico onde se usa mapeamento conceitual (Novak, 1990), teoria cognitiva da ciência (Izqueirdo, 2003), teoria da transposição didática (Chevallard, 1982) e linguagem algorítmica. Defendemos a ideia de que em casos particulares, como no estudo da teoria do conhecimento científico, que mapeamento conceitual deve ser realizado sob regras bem definidas. Devido a certas particularidades de como as teorias Físicas são construídas e expressas em termos de leis Físicas teremos que generalizar a ferramenta "mapas conceituais" para descrever como as teorias Físicas são elaboradas. Essa generalização será denominada de "Mapeamento de Estruturas do Conhecimento Científico". Tendo como tema o tópico da Física denominado Radiação de Corpo Negro e a teoria da Quantização de Planck demonstrar-se-á a utilidade e eficácia dessa metodologia e desta ferramenta.
Palavras Chaves: *Mapas Conceituais, Transposição Didática, Teoria Cognitiva da Ciência, Ensino de Ciências.*

Introduction

The main objective of this article is to present a generalization of the research, presentation and evaluation tool of the knowledge called Concept Map (CM) that we will call here Map of Structure of Scientific Knowledge (MSSK). Specifically the conceptual mapping of theories and laws of physics as presented in textbooks in general. Thus, we will deal with the problem of presenting laws, concepts and theories in graphic or visual form and in a coherent way. In order to create a research methodology that allows the researcher in science education to compare, classify and elaborate textbooks of exact sciences in general we will show that if we create more or less rigid rules this becomes a powerful tool for the elaboration of scientific knowledge. But, physical laws are expressed in terms of statements that contain mathematical formulas. Equations (vectorial) of type $\vec{F} = m.\vec{a}$ are of central importance in physics. Names of famous scientists and experiments play a key role in spreading and characterizing certain laws. How to express them using CM?

With the subdivision of the courses of engineering and exact sciences and the explosion of the publishing market created the necessity of the production of textbooks of Physics (as calculus) for the diverse types of courses. For example, today in the USA we have physics book for calculus-based course, others for algebra-based course, etc. Each of them has a teaching methodology that differentiates it from others. Thus, it becomes interesting to have or create a tool that makes it possible to analyze and dissect how knowledge is transcribed into textbooks. The best way is the visual.

There are several ways to represent a sequence of activities, ideas, concepts, etc. The simplest one is using a flowchart. Flowcharts are graphical representations through symbols and arrows used symbolically to describe a sequence of activities, operations or actions that are encapsulated in boxes. Unlike concepts maps, they don't has or use connector words in their boxes.

Another simple way to present and organize ideas graphically would be through an organogram. Organogram is a chart that represents the formal structure of an organization. This, too, does not use binding words.

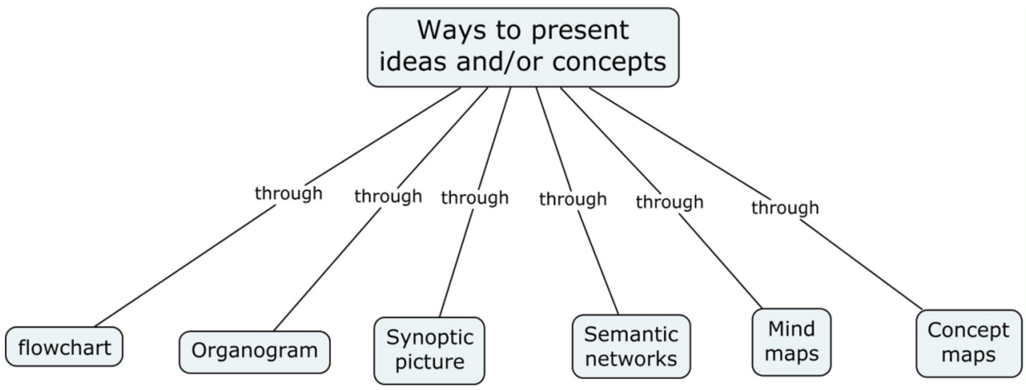


Figure 1 - Conceptual Map illustrating the most usual forms of graphical presentation of ideas and concepts.

We can use synoptic picture to summarize and present ideas. The synoptic picture is a schematic summary of an idea, a text, a document, and even a teacher's lesson. Its main advantage is to allow the visualization of the structure and organization of the content that exposes a given text. It can be crafted with the help of braces, diagrams and even use a series of columns and rows as well as tables.

Another way is through semantic networks. A semantic network is a form of knowledge representation defined as a directed graph in which the vertices represent concepts and the edges represent semantic relations between the concepts. They are considered a common form of database readable by a machine (Uchôa, 1994).

You can also use a mind map. A mind map can be considered as a semantic network variant. In using colors and figures the emphasis is on generating a semantic network that invokes human creativity. Nevertheless, the great difference between the mental map and the semantic network is that the structure of the mental map is hierarchical, with the nodes starting from a central point. Differently, in the semantic network the nodes can be connected with any other nodes (Archela, 2004).

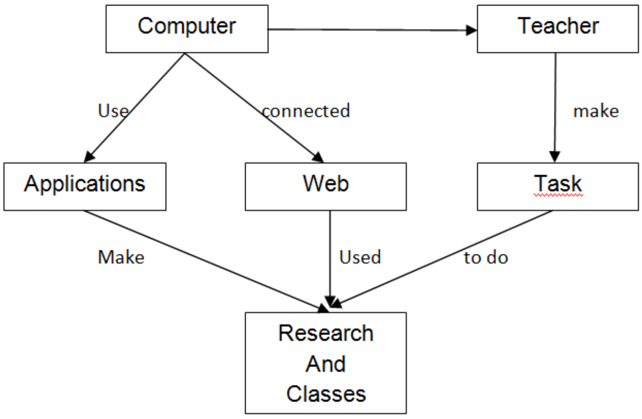


Figure 2 – Example of mental map

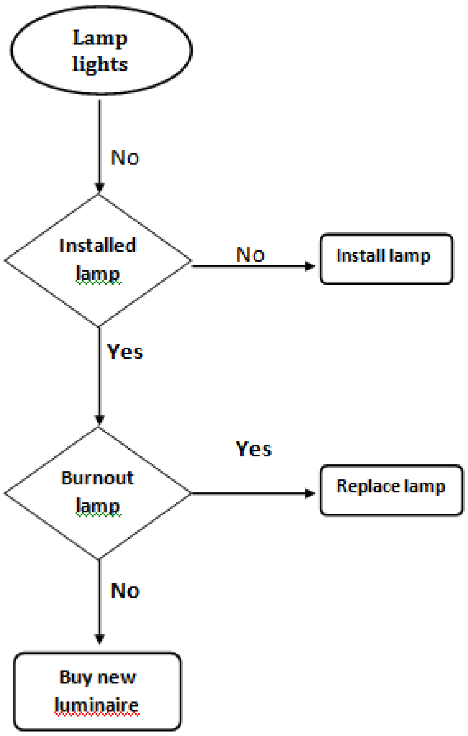


Figure 3 - Flow chart about the state of a lamp.

An algorithm is a description step-by-step and a methodology that results in solving a problem or performs a task. In general, this is represented as a resolving scheme of a problem. It can be implemented using any logical sequence of values or objects (for example, the English language, Pascal, C language, a sequence number, a set of objects such as pencil and eraser), or anything that can provide a logical sequence. Below we can see an algorithm implemented in a flowchart on the state of a lamp.

This was created and improved to make easer the task to program computers. This is based on the methodology of subdividing the task or problem. For example, we can divide systematically the problem in smaller sub-problems until we get a set of sufficiently small sub problems that allows us to solve them. In general, the algorithms are presented in the form of flowcharts before being placed in any suitable computer language.

CONCEPT MAPS

Concept map is a concise way to present and connect concepts (Novak, 1990; Moreira, 2005). As this is a mapping of concepts it uses linking words to connect ideas or concepts. Due to the variety and freedom to present graphically the concepts we have that CM is the ideal tool to evaluate, present, synthesize and summarize knowledge. See figure 1 above.

It can be said that a concept plus its connector (connecting word) is the unit or element that forms or constructs a concept map. It is constructed by the unit below:

Joseph D. Novak (2006) defines in a wide manner which is conceptual maps (CM):

> *"*Concept maps are graphical tools for organizing and representing knowledge. They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts.*"*

Due to its flexibility and degree of freedom of construction CM is one of the most used tools to represent and evaluate knowledge. As this can be constructed in the structure of knowledge more inclusive for the less inclusive, this is the ideal tool to teach significantly and / or evaluate if there was significant learning. Thus, the most common ways to build a CM are (Romero, 2007):

1 - Concept Map Spider-like: The "spider-like" conceptual map is organized by placing the central theme or unifying factor in the center of the map. The sub-themes radiate outward circling the center of the map.

2 - Hierarchical Concept Map: The concept map type hierarchical presents information in a decreasing order of importance. The most important information is placed at the top. Distinctive factors determine the placement of the information.

3 - Flowchart Conceptual Map: The flowchart concept map organizes information in linear format.

4 - Concept Map System-like: The system-like concept map organizes information in a shape similar a flowchart with the addition of 'INPUTS' and 'OUTPUTS'.

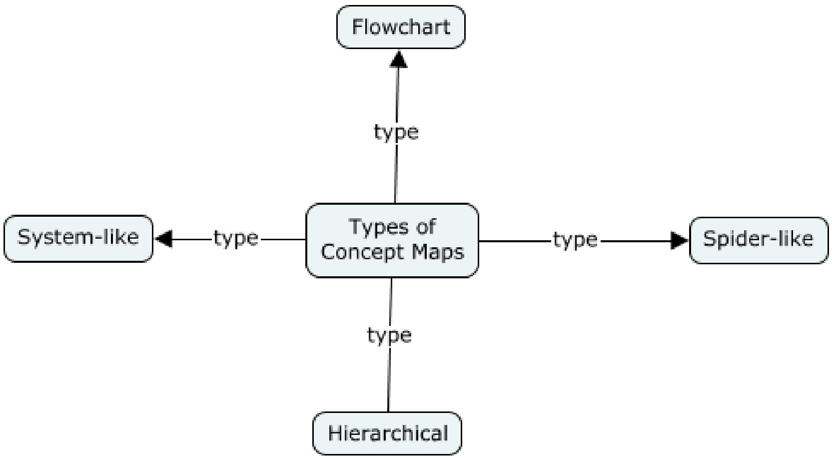


Figure 4 - Spider-like Concept Map.

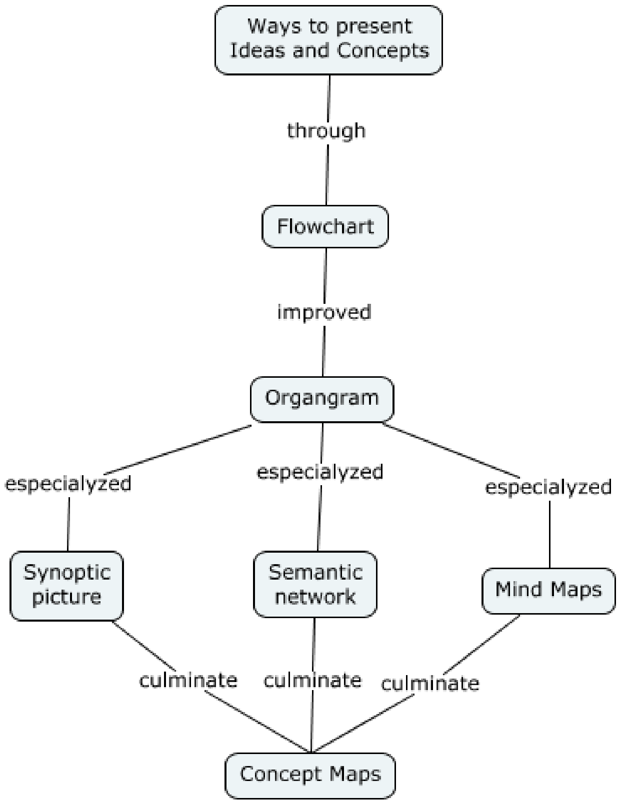


Figure 5 – Concept Map of the Hierarchical type.

When thinking about teaching and meaningful learning the construction of conceptual maps must be done in the manner proposed by Novak and Gowin (Novak, 1998; Novak and Gowin, 1999). In this it is considered a hierarchical structuring of the concepts that will be presented both through a progressive differentiation and an integrative reconciliation.

When the CM is well constructed allows the visualization and perception of how the keys concepts from a particular topic or field of knowledge follow one another, intertwine and organizes themselves in the structuring of this knowledge. Thus, we tried to create some basic rules for the construction and standardization of CM's that can be seen in many articles (Novak 2006; Moreira, 2006; Author, 2014). Despite these rules concept map is a very flexible tool and can be used in various ways. But, as showed by Author (2017a and 2017b), in the case of a systematic study we must create some very specific rules for the construction of CM, so that they become a kind of algorithmic language. This is the central theme of this article.

Due to its concise, hierarchical and graphical way of presenting the key concepts to be taught we have that CM are a powerful tool to make curricular analysis in general (Novak, 2006; Moreira, 2006). Author (2017a) generalized this idea and showed that CM is the natural tool to perform the analysis of the conceptual framework that textbooks are written. Due to its concise, hierarchical and graphical way to present the key concepts the construction of an CM for a topic or the whole book, allows you to see promptly and succinctly the conceptual framework that a particular author used to concatenate and organize the key concepts that go into the preparation of your textbook. But, as we said above, Physical theories are expressed in terms of mathematical equations and their functions. Therefore, we will have to briefly discuss what these are and their role in transmitting knowledge, especially school knowledge.

CONCEPT MAPS AND PHYSICAL LAWS - MAPS OF STRUCTURES OF SCIENTIFIC KNOWLEDGE

When constructing a whole methodology of research to study how knowledge is generated and transmitted, in the particular case here of Physics, we have to analyze with a little more care what are concepts and connection words in a CM. In the first place, the connecting words are not restricted to mere prepositions, but these can be verbs, two words, and so on (Novak, 2006). Without going into details of what a concept is in its more general or comprehensive definition, more details see Novak (2006) and Moreira (2005), Physics concepts are definitions based on hypotheses, laws or theories that are generally based on laws of physics which in turn are expressed in terms of mathematical functions and their equations.

Symbols and symbolic representation of relations and operations. When we are studying or teaching concepts of kinematics the letter or symbol or sign “s” means space and is called the Physical quantities. But space in Physics means place, region with three dimensions (height, width, and depth) and is a dimensional quantity, that is, it is obtained by means of a measure by comparison with a scale (for example, a bar of one meter). In this way, a signal in physics has a series of meanings and concepts. Further details see Lindsay and Margenou (1957).

On the other hand, we have primitive and derivative quantities in Physics. That is, as in mathematics, in Physics the physical quantities are manipulated through the rules of algebra and calculus to produce or derive other physical quantities. These are called derived quantities. Through well-planned laboratory measures and strong control of external conditions we obtain functional relations and equations that describe the behavior and functional dependence of these quantities[1].

[1] For example, David Hume (19xx)

Some of these functions are so important that they are called the fundamental law of physics (Lindsay, 1957). For example, Newton's 2nd Law: $\vec{F} = m.\vec{a}$. Other formulas commonly denominated of law are only hypotheses, like the law of the Universal Gravitation,

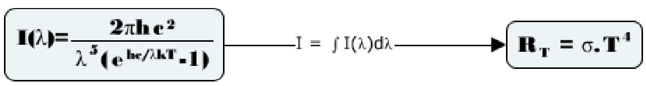
$$\vec{F} = \frac{GMm}{r^3}\vec{r}$$

Laws of Physics. A physical law is nothing more than a symbolic description (in the "simplest" form) of a routine observed in a limited field of phenomena. It is good to emphasize again its descriptive nature. He never intends to give a reason for any of the phenomena described in the metaphysical sense (Lindsay, 1957). For example, Newton's 2nd Law tells us that when we apply a force $\vec{F}$ to a body of mass m this will acquire an acceleration $\vec{a}$. That is, it does not constitute what is popularly called explanation. Newton's law of gravitation is not an explanation of gravitation, in the sense that it explains why particles attract. It is just to give an accurate description of the observed attraction. Physical law attempts to answer the "how" question and not the "why" question. But when we put the symbol $\vec{F}$ for a physicist or student of Physics it becomes explicit all that we mentioned above and that on the right side of this expression we can substitute any of the types of forces existing in nature. Further details see Lindsay and Margenou (1957).

Physical Theory and its Construction. In order to construct a physical theory we must define its primitive concepts and symbols. In Mechanics these would be those of space (s), time (t) and mass (m); In Gas Theory would be pressure (P), volume (V) and Temperature (T), and so on. From these we obtain or construct other symbols or derived quantities. In Mechanics we have velocity (v), acceleration (a), moment (p) and others. We are then ready for the next step - the choice of hypotheses or we assume fundamental relations between the symbols by logical deduction from which all the special results of the theory, namely the laws, must be obtained. Further details see Lindsay and Margenou (1957).

Therefore, due to the hard work of systematization and definition of a concept map by the scientific community, I will have to create a particular denomination for conceptual maps in which concept boxes are made by equations, formulas, symbols or names[2]. As you might expect, we can use physics symbols when we use functions, equations, names of physics, etc as connection words. We will call these generalized concept map as "Maps of Structure of Scientific Knowledge".

Thus, if one is studying or evaluating a text whose content is the epistemological and pedagogical construction of a theory belonging to Physics one can use symbols and names of the laws of Physics in the construction of a graphical representation of this in the form of a map of the structure of scientific knowledge (MSSK). That is nothing more than a generalized conceptual map. We put down an atomic unit of this in which on one side we have the famous Planck equation connected through the integral signal (a sum over all wavelengths) to the Rayleight's Law.



[2] I believe that it is for a definite time, therefore, in essence we have a conceptual map.

In this way, it is clear to a physics teacher if the textbook was elaborated in a more conceptual manner, that is, if it omits certain mathematical demonstration or not. This is very important in the convenient choice of textbook for an exact course. In the sequence we will discuss some rules of construction of these maps of structure of scientific knowledge in order to create a tool that helps us in the construction and evaluation of didactic texts.

Conceptual Maps, Didactic Transposition and Cognitive Models of Science.

But scientific theories are constructed from scientific models, assumptions and theorems that are propose to explain a certain set of events. These explanations are structured around concepts, nodes or links (Latour, 1999), which allow us to understand the scientific activity. (Izquierdo, 2003).

On the other hand, scientific theories are presented in textbooks as a set of models related to some facts and some identifiable instruments that give meaning to the theory. Relations between the models and the facts are developed through postulates and theoretical hypotheses, which can be more or less true or false, since they have empirical content. Therefore, a scientific theory is a family of models together with postulates and/or assumptions establishing the similarity of these models with experimental facts.

These explanations, that is, theoretical ideas about the world created to understand it, are structured around concepts. For Latour (1999), these concepts, or what he calls knots or links, are those things that allow us to understand the scientific activity, without which scientific activity simply would not exist (Izquierdo, 2003). Thus, being CM diagrams of meanings, indicating hierarchical relationships between concepts or between words that represent concepts, this are the ideal tool to map as these nodes or links are prepared and organized so as to create a coherent whole and that make sense to a certain level of schooling. That is, to study how the knowledge produced to a level of schooling is transcribed to another. More details see Novak (1990) or Moreira (2005).

Author (2017c) demonstrates, for the case of the topic of physics called Photoelectric Effect, that currently the scientific knowledge is structured didactically in their transcriptions to textbooks in: a) models; b) the core of the theory; c) experimental facts; d) the key concepts; e) the methodology and f) the application of the theory. Thus, it is necessary to understand how these "pieces of knowledge" are inserted, deleted, and summarized to make each text a coherent whole.

Author (2017b, 2017c) showed that in the case when the original theory was built in a paradigm revolution (Kuhn, 1970) that the theory need first be consolidated in the new paradigm before suffer a DT to the high school level. That his original explicative models must be adapt or rewritten in this new paradigm.

So, the CM built to analyze how knowledge suffer a DT must be constructed under some rules. In this the conceptual structure described above should be very clear. Like an algorithm it must be created with the finality of describe the knowledge structure. The CM builder must be trained in dissect the knowledge in its fundamental parts.

Concept Map as an Algorithmic Language to study the Knowledge.

The main objective of this article is to demonstrate through the didactic transposition of the Max Planck article to textbooks the power of synthesis and analysis of the conceptual mapping using it as it was an algorithmic language, that is, in it generalized version denoted as maps of structure of scientific knowledge (MSSK).

Just as in a flowchart dedicated to computational algorithm we have specific symbols that define specific operations or actions, created in order to facilitate and standardize their reading, we have that we can create with the same objective symbols or specific colors for a particular mapping of concepts. This is the case of conceptual map developed to describe the conceptual construction of a book, a book topic, a given field of knowledge or a scientific theory, as demonstrated by Author (2017a, 2017b).

In the case of scientific theories, called here of knowledge, we have these consist of a) explanatory models; b) the core of the theory; c) the key concepts; d) methodology; e) experimental facts and d) the application of the theory. Mainly, how these concepts or nodes or links are inserted, deleted, summarized and twisted to make each text a coherent whole.

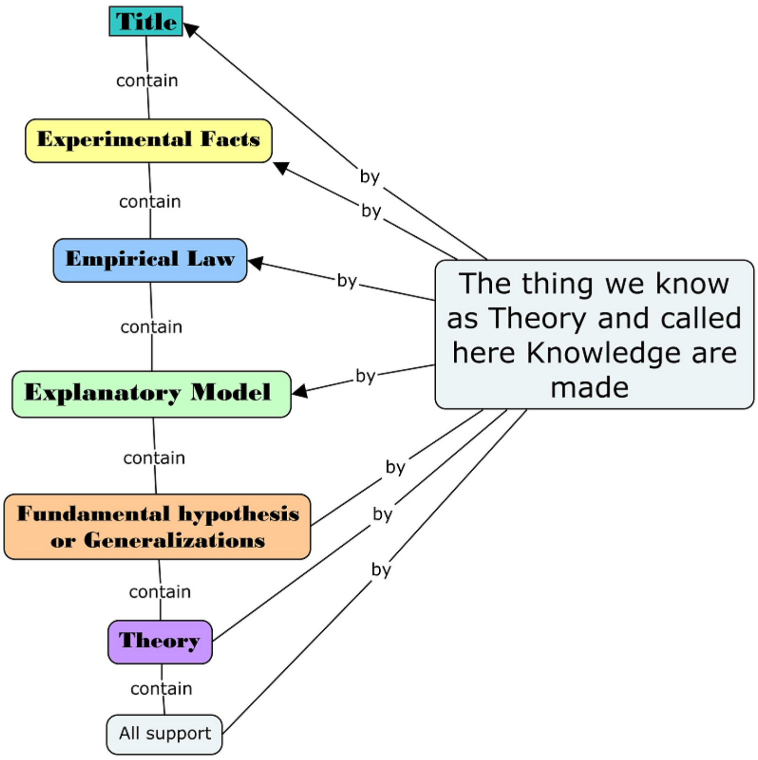


Figure 6: Figure with symbolic structure of the constituent parts of an MSSK to the theory of knowledge.

So we use green boxes to identify the models. Boxes in blue to identify empirical laws, conclusions or results. I use box in Purple for theory. We will put experimental facts that resulted in theory in yellow boxes. Title in aquamarine. Light blue all support material, such as equations, deductions, etc. Finally, we put in coral generalizations or universalizations theory. In this case we have no theory applications.

In order to demonstrate the potential and power of explanation and synthesis of CM built as an algorithmic language, it will, in what follows, present CM prepared without the use of special colors, that is, clean. The CM clean of Planck's article gives us a schematic, visual summary and ordered the ideals, concepts and everything else that makes up its article. But if the reader did not know previously that it is composed of theory, models, etc. there is a great possibility that pass unnoticed any of these items that make up the knowledge, and the reader could not understand in depth all its contents.

On the other hand, the CM prepared according to the algorithmic rules also provide us a schematic, visual summary and ordered the ideals, concepts and everything else that makes up the article. But its colored boxes call the reader's attention to its constituent parts, so that in a first reading in addition to an overview of the text content colors allow and call the reader's attention to its constituent parts.

The CM in the form of algorithm (MSSK) will indicate which sequence the author entered, organized and braided the component parts of his theory (knowledge). Moreover, MSSK analysis done for a particular book allows you to view how these concepts (or nodes or links) are inserted, deleted, summarized and twisted to make each text a coherent whole (Author, 2017a, 2017b and 2017c). Used in a comparative analysis it allows you to check (Author, 2017b, 2017c and 2017d): a) as explanatory models are adapted, simplified and deleted; b) how knowledge of the contents are transposed into a teaching methodology of science, suffering a didactic transposition; c) when and how knowledge is implemented and consolidated in a new scientific paradigm.

Example: The Max Planck theory of quantization (1901)

In many textbooks as well as teach classes of Quantum Mechanics the theory of Max Planck quantization is presented, undergoing a DT, as being simply an ad hoc assumption made by Max Planck (1901) to explain the spectrum of blackbody radiation (BBR). There is no exposure of explanatory models nor experimental facts that resulted in the theory[3]. For example, the book Fundamentals of Physics (Halliday, 1997). That is,

$$E = h.\nu$$

In some texts this theory is summarized in the BBR definition, the presentation of the empirical laws that preceded the Planck Law and his hypothesis. There is no elaboration of an explanatory model and not a discussion of how this was developed in the old paradigm. See Fig. 7. By the way it is presented briefly the theory of BBR can see that this is a text to form engineers in general.

Analyzing the Max Planck (1901) original article we clearly see the structure and the brilliance of his reasoning. That is: a) Definition of BBR and presentation of experimental facts; b) followed by an empirical law; c) attempt to write the theory into universal principles; d) the model in the old paradigm, boxes in green; e) and deduction of universal law. See fig.8.

Analyzing the CM clean of the Jewett (2010) textbook, fig.5, we see the difficulty in checking the presentation of experimental facts concatenate with the empirical laws and the

[3] Because of the tradition we use the name Theory for all this body of knowledge. When appropriate we will use the word knowledge as defined by Author (2017d).

introduction of the new paradigm, which takes place within their explanatory model. Analyzing the MSSK, fig.6, we can see clearly in the CM the yellow boxes scattered and concatenated with blue boxes and that in the last line as Planck's hypothesis (new paradigm) is inserted into the theory. Despite the greater emphasis given to the explanation of the experimental facts and empirical laws that resulted in the Planck Law it can be noted that this text was prepared in the same structure of the Planck article, that is, facts and experimental laws → explanatory model → theory. We see by the level of preparation of presentation of the theory of BBR that this book is really designed to train scientists in general.

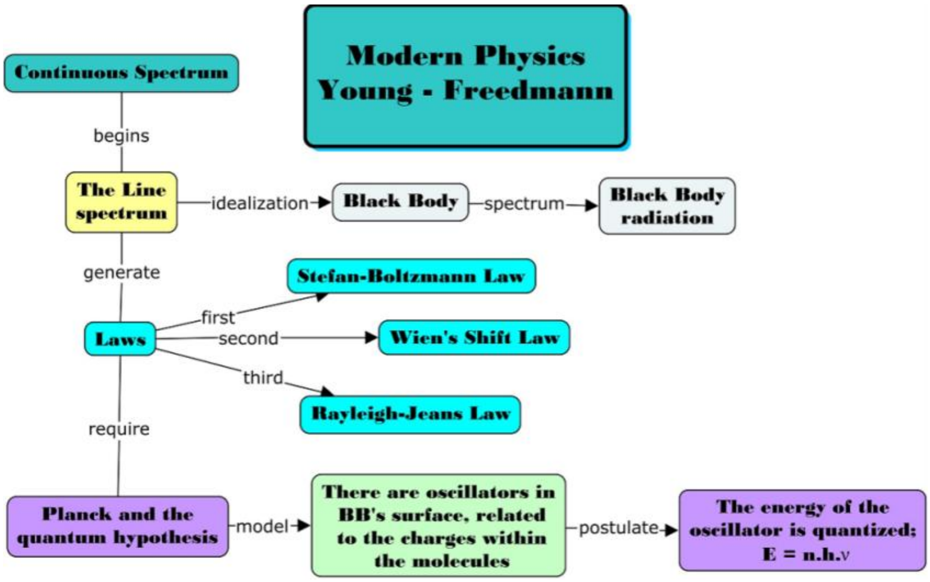


Figure 7: The MSSK of BBR theory from the text of Young-Freedemann textbook (2010).

Results and Conclusions

Here we try to show the advantages of creating rules to the construction of conceptual maps with the use of color coding. From these rules we provide the CM with an algorithmic structure so that we denominate it in the text as MSSK, to distinguish it from the CM prepared without the use of this structure.

With the use of MSSK we were able to showas the knowledge produced in the academic spheres will suffering a TD, that is, is transformed and diluting to get to school class (sphere). Using CM as an analysis tool for the knowledge study we reduced the degree of subjectivity of this analysis and make it easy to identify, classify and order the elements of a given knowledge or theory, as we are accustomed to call.

We will show in a later article that the creation of a generalized theory for didactic transposition was only possible through the use in a systematic form of CM in algorithmic form in the study of how knowledge is redrafted in its implementation at different levels of understanding of the students.

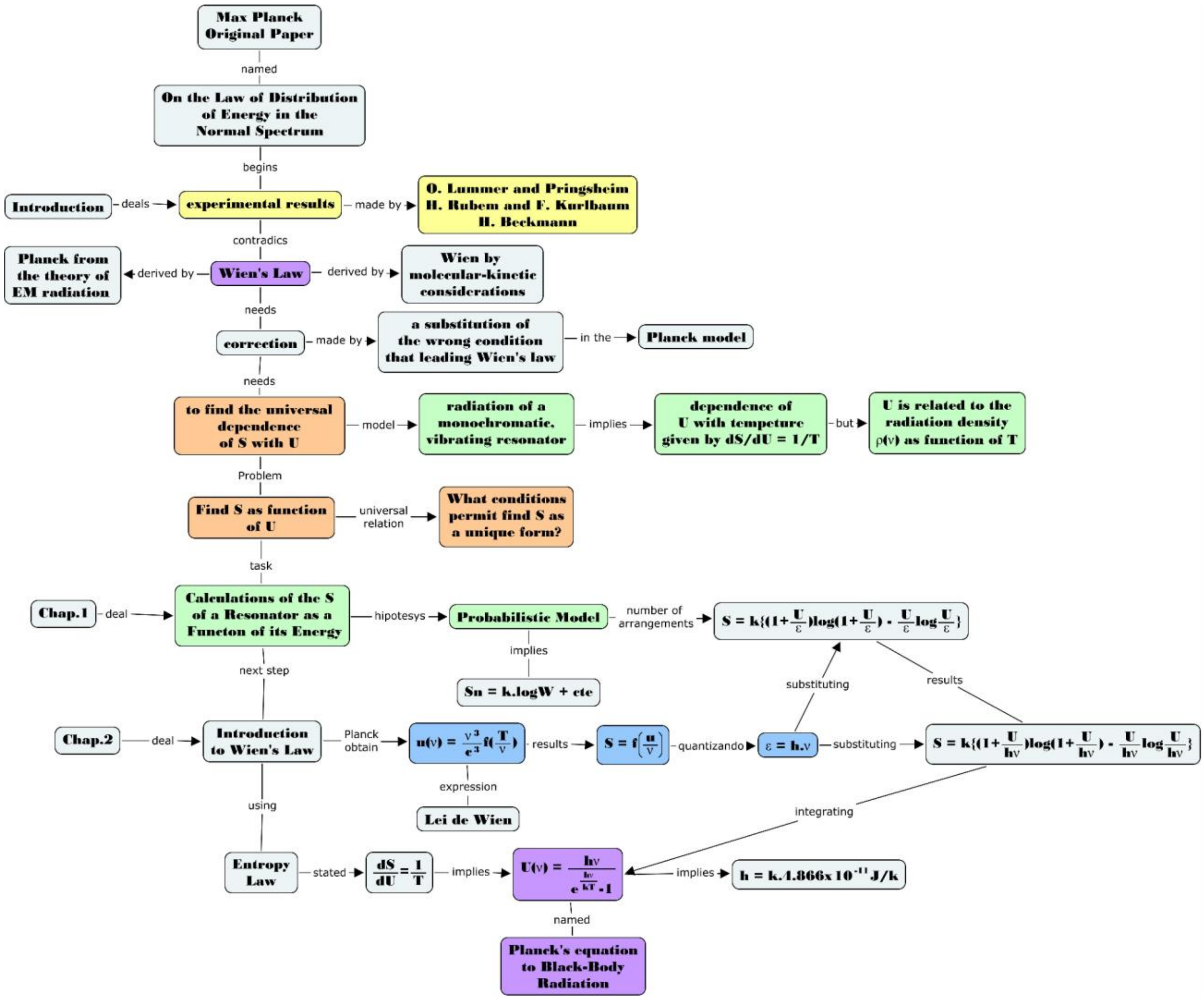


Figure 4: The Max Planck (1901) MSSK of BBR theory.

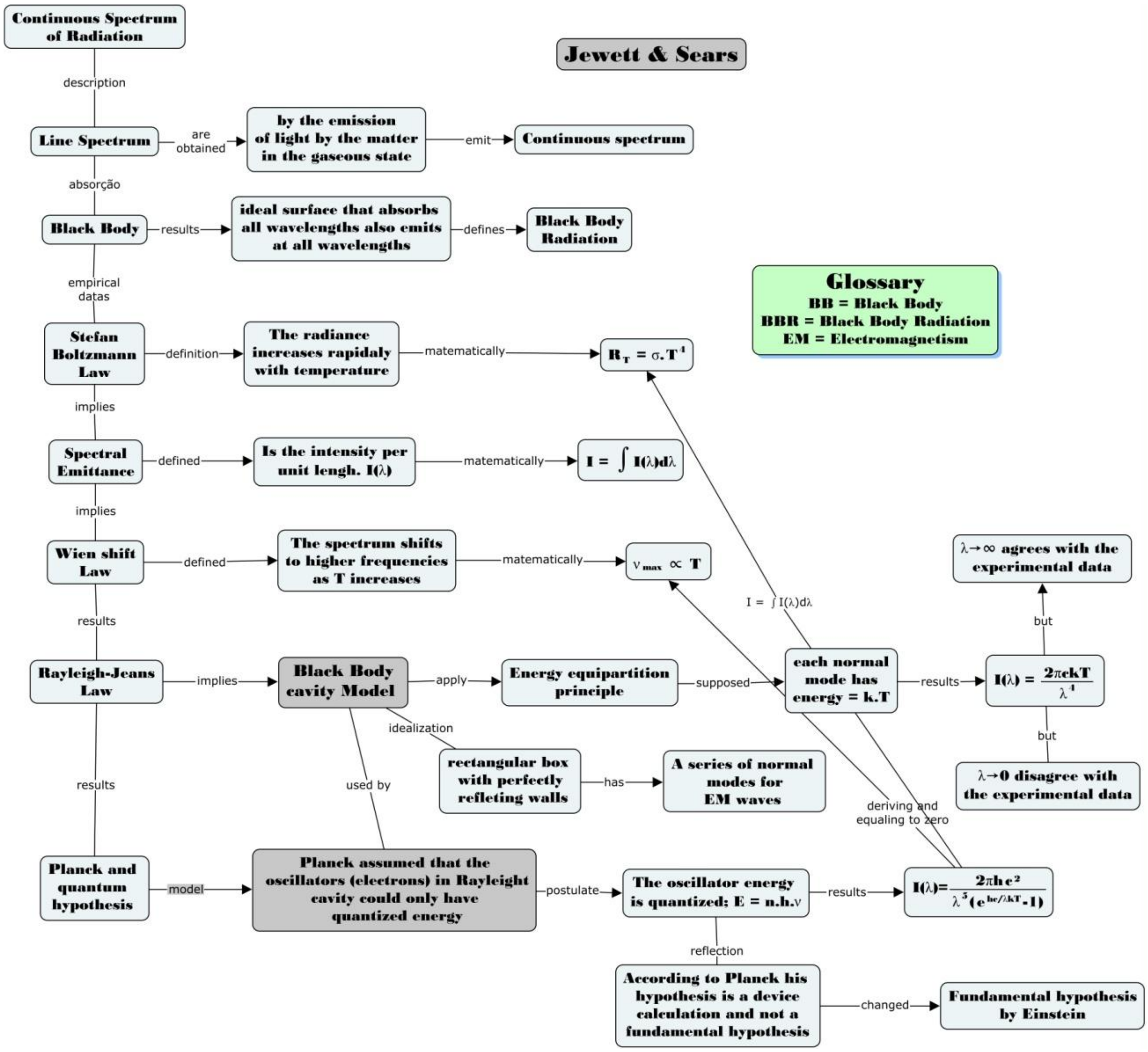


Fig.6 – The CM clean of BBR theory from the text of Jewett & Sears textbook (2010).

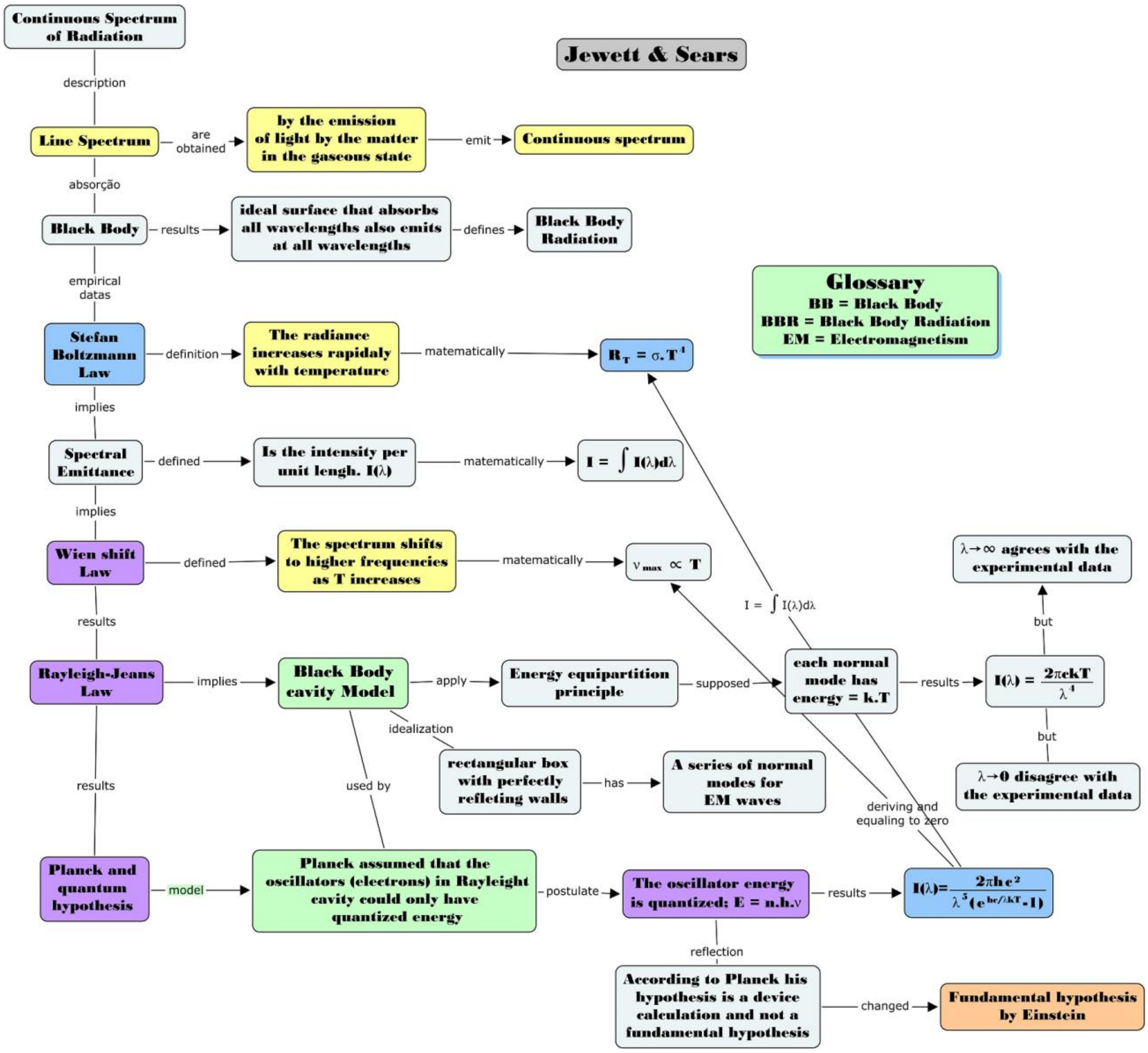


Figure 5: The MSSK of BBR theory from the text of Jewett & Sears textbook (2010).

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